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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/086,125	02/27/2002	Izhak Baharav	10010314-1	2242

7590 11/26/2003

AGILENT TECHNOLOGIES, INC.
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EXAMINER	
YAM, STEPHEN K	

ART UNIT	PAPER NUMBER
2878	

DATE MAILED: 11/26/2003

Please find below and/or attached an Office communication concerning this application or proceeding.

Office Action Summary	Application No.	Applicant(s)	
	10/086,125	BAHARAV ET AL.	
	Examiner	Art Unit	
	Stephen Yam	2878	

-- *The MAILING DATE of this communication appears on the cover sheet with the correspondence address* --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *02 September 2003*.

2a)☒ This action is **FINAL**. 2b)☐ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-9,11-19,27 and 28* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1-9,11-19,27 and 28* is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. §§ 119 and 120

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

13)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application) since a specific reference was included in the first sentence of the specification or in an Application Data Sheet. 37 CFR 1.78.

a) ☐ The translation of the foreign language provisional application has been received.

14)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121 since a specific reference was included in the first sentence of the specification or in an Application Data Sheet. 37 CFR 1.78.

Attachment(s)

1) ☐ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☐ Information Disclosure Statement(s) (PTO-1449) Paper No(s) _____ .
4) ☐ Interview Summary (PTO-413) Paper No(s). _____ .
5) ☐ Notice of Informal Patent Application (PTO-152)
6) ☐ Other: .

DETAILED ACTION

This action is in response to Amendments and remarks filed on September 2, 2003. Claims 1-9, 11-19, 27, and 28 are currently pending.

Claim Rejections - 35 USC § 102

1. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

2. Claims 14-19 and 28 are rejected under 35 U.S.C. 102(b) as being anticipated by Nozaki et al. US Patent No. 4,677,289.

Regarding Claim 14, Nozaki et al. teach (see Fig. 4) a sensor, comprising a first two-color photo-detector (42B, 42G) sensitive to a first total wavelength range (blue + green), said first two-color photo-detector having a first photo-detector element (42B) capable of absorbing light within a first range of wavelengths (blue) of said first total wavelength range and a second photo-detector element (42G) capable of absorbing light within a second range of wavelengths (green) of said first total wavelength range, said first photo-detector element being in an elevated relation with said second photo-detector element (see Fig. 4), and a first dielectric layer (44G) between said first photo-detector element and said second photo-detector element, a second two-color photo-detector (42R, 42IR) having a third photo-detector element (42R) in an elevated relation with a fourth photo-detector element (42IR), said second two-color photo-detector being sensitive to a second total wavelength range (red + infrared) different from said first total

wavelength range, and a second dielectric layer (44IR) between said third photo-detector element and said fourth photo-detector element.

Regarding Claim 15, Nozaki et al. teach (see Fig. 4) a substrate (44R), said second photo-detector element formed within said substrate.

Regarding Claim 16, Nozaki et al. teach said first photo-detector element formed of amophous silicon (see Col. 9, lines 7-9) having a thickness selected to absorb light within said first range of wavelengths (see Col. 9, lines 61-66), said second photo-detector detecting light within said second range of wavelengths passed by said first photo-detector element (see Col. 9, lines 43-51).

Regarding Claims 17 and 18, Nozaki et al. teach (see Fig. 4) a color filter (46) in an elevated relation with said first photo-detector element, said color filter absorbing light within a third range (infrared) of wavelengths and passing light within said first and second range of wavelengths (see Col. 8, lines 40-43) and a transparent metal conductor layer (44B) between said color filter and said first photo-detector element.

Regarding Claim 19, Nozaki et al. teach (see Fig. 4) circuitry (54) for driving said first and second photo-detector elements, said first photo-detector element being in an elevated relation with said circuitry.

Regarding Claim 28, Nozaki et al. teach said first photo-detector element formed of amorphous silicon (see Col. 9, lines 7-9) having a first thickness selected to absorb light within said first range of wavelengths (see Col. 9, lines 61-66) and said third photo-detector element is formed of amorphous silicon having a second thickness selected to absorb light within a third range of wavelengths.

Claim Rejections - 35 USC § 103

3. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

4. Claims 1-9, 11-13, and 27 are rejected under 35 U.S.C. 103(a) as being unpatentable over Nozaki et al. in view of Yokota et al. UK Patent Application No. 2,166,289.

Regarding Claims 1-9, 12, and 27, Nozaki et al. teach (see Fig. 4) a sensor, comprising a first two-color photo-detector (42B, 42G) sensitive to a first total wavelength range (blue + green), having a first photo-detector element (42B) capable of absorbing light within a first range of wavelengths (blue) of said first total wavelength range and a second photo-detector element (42G) capable of absorbing light within a second range of wavelengths (green) of said first total wavelength range, said first photo-detector element being in an elevated relation with said second photo-detector element, and a second two-color photo-detector (42R, 42IR) having a third photo-detector element (42R) in an elevated relation with a fourth photo-detector element (42IR), said second two-color photo-detector being sensitive to a second total wavelength range (red + infrared) different from said first total wavelength range. Regarding Claim 2, Nozaki et al. teach (see Fig. 4) a substrate (44R), said second photo-detector element formed within said substrate. Regarding Claim 4, Nozaki et al. teach said first photo-detector element formed of amorphous silicon (see Col. 9, lines 7-9) having a first thickness selected to absorb light within said first range of wavelengths (see Col. 9, lines 61-66) and said third photo-detector element is

formed of amorphous silicon having a second thickness selected to absorb light within a third range of wavelengths. Regarding Claims 5 and 6, Nozaki et al. teach said first and second photodetector elements as PIN photodiodes (see Col. 9, lines 7-9). Regarding Claims 7 and 8, Nozaki et al. teach a color filter (46) in an elevated relation with said first photo-detector element, said color filter absorbing light within a third range of wavelengths and passing light within said first and second range of wavelengths and a transparent metal conductor layer (44B) between said color filter and said first photo-detector element. Regarding Claim 9, Nozaki et al. teach (see Fig. 4) circuitry (54) for driving said first and second photo-detector elements, said first photo-detector element being in an elevated relation with said circuitry. Regarding Claim 28, Nozaki et al. teach said first photo-detector element formed of amorphous silicon (see Col. 9, lines 7-9) having a first thickness selected to absorb light within said first range of wavelengths (see Col. 9, lines 61-66) and said third photo-detector element is formed of amorphous silicon having a second thickness selected to absorb light within a third range of wavelengths. Regarding Claim 12, Nozaki et al. teach said third photo-detector element capable of accumulating charge upon reception of light within a third range of wavelengths (red) and said fourth photo-detector element capable of accumulating charge upon reception of light within a fourth range of wavelengths (infrared). Nozaki et al. do not teach said first photo-detector element being electrically isolated from said second photo-detector element and said third photo-detector element being electrically isolated from said fourth photo-detector element, using a dielectric layer. Yokota et al. teach (see Figs. 1 and 2) a sensor comprising a first two-color photo-detector sensitive to a first total wavelength range (see Fig. 3), having a first photo-detector element (PD1- (28, 29, 30)) (see Page 3, lines 44-48) capable of absorbing light within a

first range of wavelengths (see Page 3, lines 56-60) of said first total wavelength range and a second photo-detector element (PD2- (22, 23, 24)) capable of absorbing light within a second range of wavelengths (see Page 3, lines 60-62) of said first total wavelength range, said first photo-detector element being in an elevated relation with the second photo-detector element, the first photo-detector element being electrically isolated (see Fig. 2 and insulating film (26) in Fig. 1) from said second photo-detector element, and a dielectric layer (26) between said first photo-detector element and said second photo-detector element, said dielectric layer electrically isolating said first photo-detector element from said second photo-detector element. It would have been obvious to one of ordinary skill in the art at the time the invention was made to electrically isolate the top photo-detector element from the bottom photo-detector element as taught by Yokota et al. in the sensor of Nozaki et al., to reduce electrical interference and increase individual detector sensitivity.

Regarding Claim 11, Nozaki et al. in view of Yokota et al. teach the sensor in Claim 1, according to the appropriate paragraph above. Nozaki et al. also teach a color filter (46) in an elevated relation with said first photo-detector element, said color filter absorbing light within a third range of wavelengths and passing light within said first and second range of wavelengths. Nozaki et al. do not teach a second color filter in an elevated relation with said third photo-detector element, said second color filter absorbing light within either said first or second ranges of wavelengths and passing light within said third range of wavelengths and passing light within either said first or second ranges of wavelengths not absorbed by said second color filter. It is well known in the art to include filter layers in a semiconductor structure to filter out extraneous light. It would have been obvious to one of ordinary skill in the art at the time the invention was

made to provide a second color filter on top of the second photo-detector element (42G) absorbing light in the first range (blue) of wavelengths, passing light in the third range (red + infrared) of wavelengths, and passing light within said second range (green) of wavelength in the sensor of Nozaki et al. in view of Yokota et al., to remove any residual blue light not absorbed by the first photo-detector element (42B) to prevent its interference with the remaining three photo-detector elements, to decrease noise in the outputs of the remaining three photo-detector elements.

Regarding Claim 13, Nozaki et al. in view of Yokota et al. teach the sensor in Claim 1, according to the appropriate paragraph above. Nozaki et al. also teach the first, second, third, and fourth photo-detector elements generating first, second, third, and fourth color values, respectively (see Col. 9, lines 10-16 and Fig. 1). Nozaki et al. do not teach a third and fourth two-color photo-detector having the same wavelength sensitivities as the first two-color photo-detector. It is well known in the art to use multiple photo-detectors in an array to detect an optical image or pattern. It would have been obvious to one of ordinary skill in the art at the time the invention was made to include two additional structures of Nozaki et al. (Fig. 4) placed adjacent to each other, each photo-detector element producing different color values, in the sensor of Nozaki et al. in view of Yokota et al., to capture a colored visual image or multi-dimensional pattern by using multiple adjacent detectors in an array.

Response to Arguments

5. Applicant's arguments filed September 2, 2003 have been fully considered but they are not persuasive.

6. Applicant's arguments with respect to claims 1-9, 11-19, 27, and 28 have been considered but are moot in view of the new ground(s) of rejection.

Regarding Applicant's arguments on the Nozaki et al. reference, Applicant argues that Nozaki et al. does not teach a color filter, as "color" is a property of visible light. Examiner asserts that a "color filter" is a general term describing the filtering of electromagnetic wavelengths of light and is not limited to the visible spectrum. Examiner further submits the definition of "color filter" according to the Photonics Dictionary (www.photonics.com) as "A device with characteristics of selective transmittance, capable of passing a certain part of the electromagnetic spectrum while being opaque to the other portions." Hence, the filter of Nozaki et al. is a color filter even though it is an IR filter.

Conclusion

7. Applicant's amendment necessitated the new ground(s) of rejection presented in this Office action. Accordingly, **THIS ACTION IS MADE FINAL**. See MPEP § 706.07(a). Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the THREE-MONTH shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37

CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the date of this final action.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Stephen Yam whose telephone number is (703)306-3441. The examiner can normally be reached on Monday-Friday 8:30am-5pm.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, David Porta can be reached on (703)308-4852. The fax phone number for the organization where this application or proceeding is assigned is (703)308-7724.

Any inquiry of a general nature or relating to the status of this application or proceeding should be directed to the receptionist whose telephone number is (703)308-0956.

SY

DAVID PORTA
SUPERVISORY PATENT EXAMINER
TECHNOLOGY CENTER 2800

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(51) INT CL[4]
H01L 31/10

(52) Domestic classification
H1K 1EB 2S1B 2S1D 2S1E 2S20 2S2D 2S2P 5B2 9C3 9N3 EBC

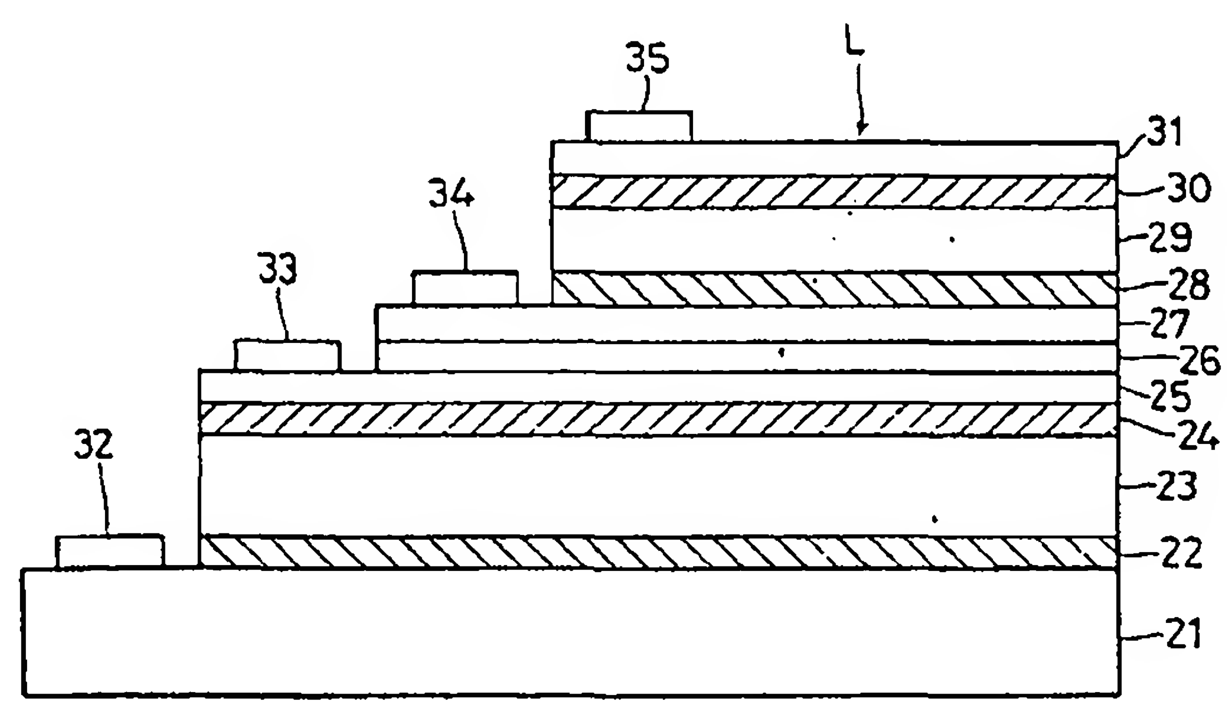
(56) Documents cited
GB A 2083705
GB A 2047463
GB A 2030359

(58) Field of search
H1K

(54) **Colour sensitive photodetector**

(57) The sensor comprises a substrate 21, a first amorphous photovoltaic element having a PIN structure 22-24 formed on the substrate, a transparent insulated layer 26 formed on the first element, and a second similar element 28-30 formed on the transparent insulation layer. The two elements have different frequency responses.

FIG. 1



GB 2 166 289 A

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FIG. 1

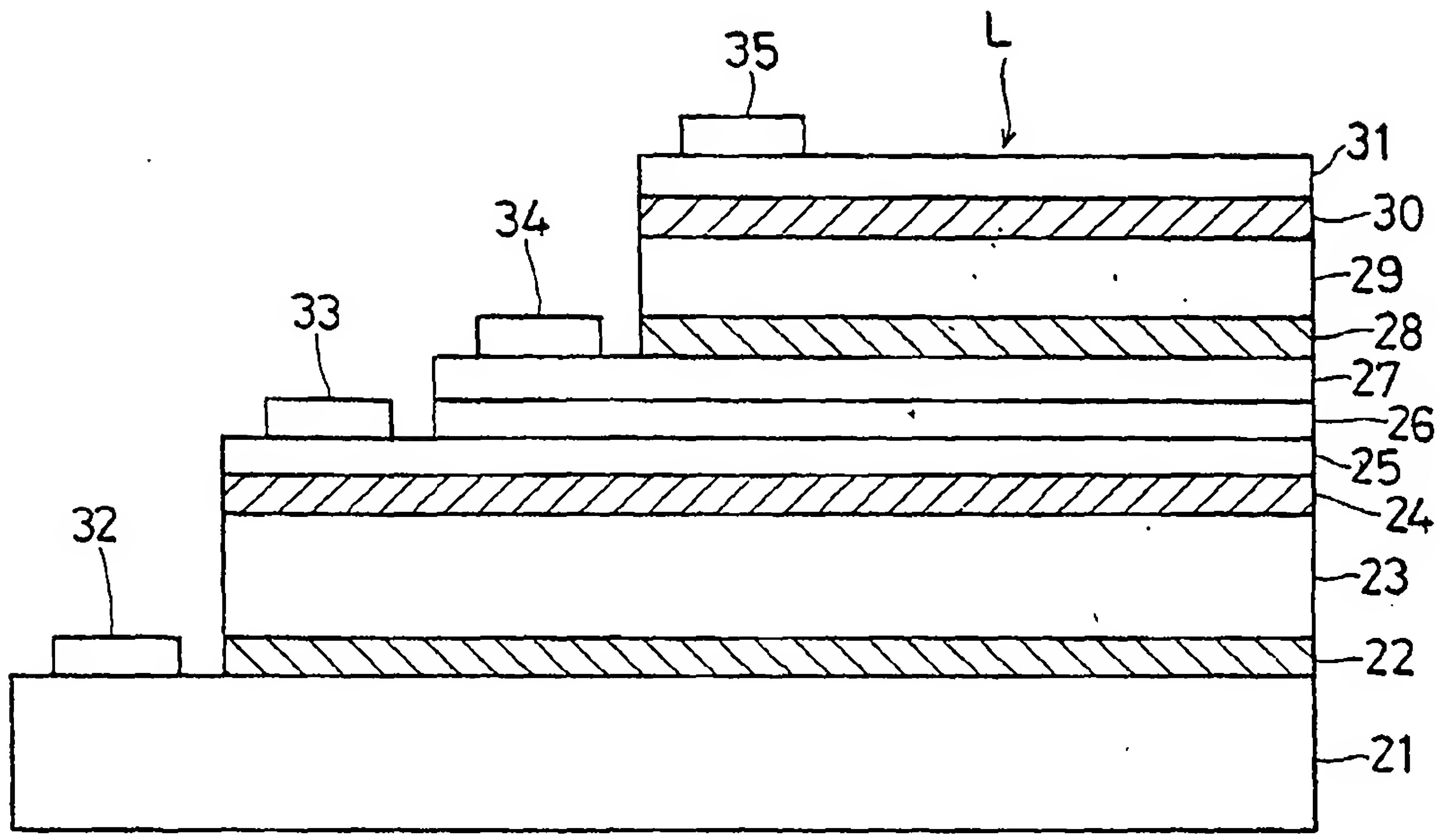


FIG. 2

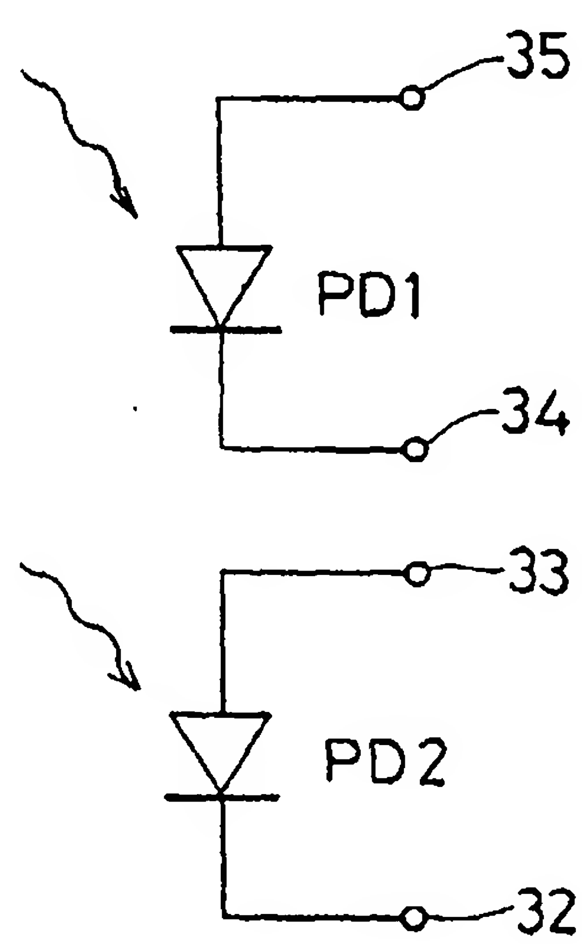
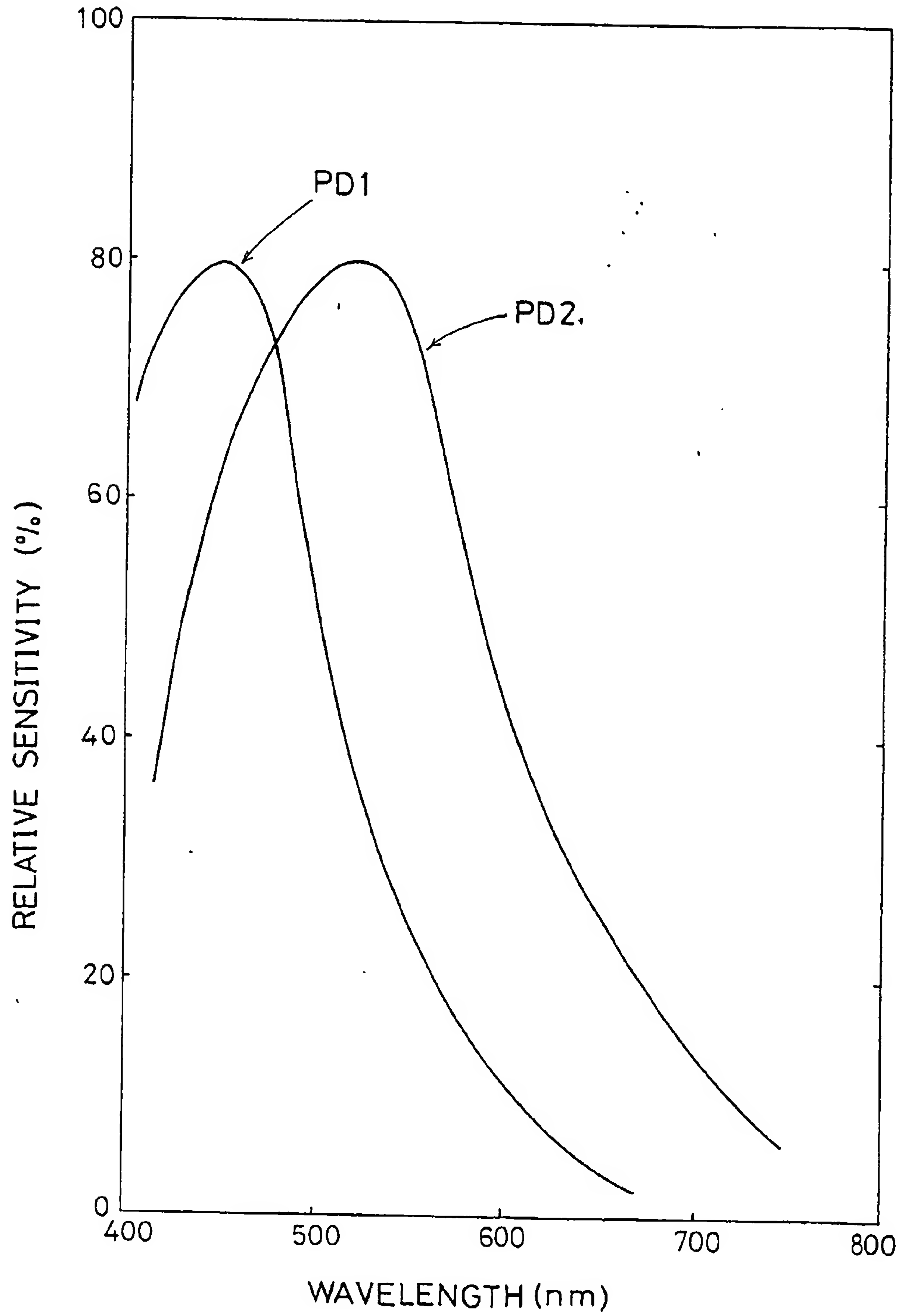


FIG. 3


PD1
PD2.
100
80
60
40
20
0
RELATIVE SENSITIVITY (%)
400
500
600
700
800
WAVELENGTH (nm)

2166289

FIG.4

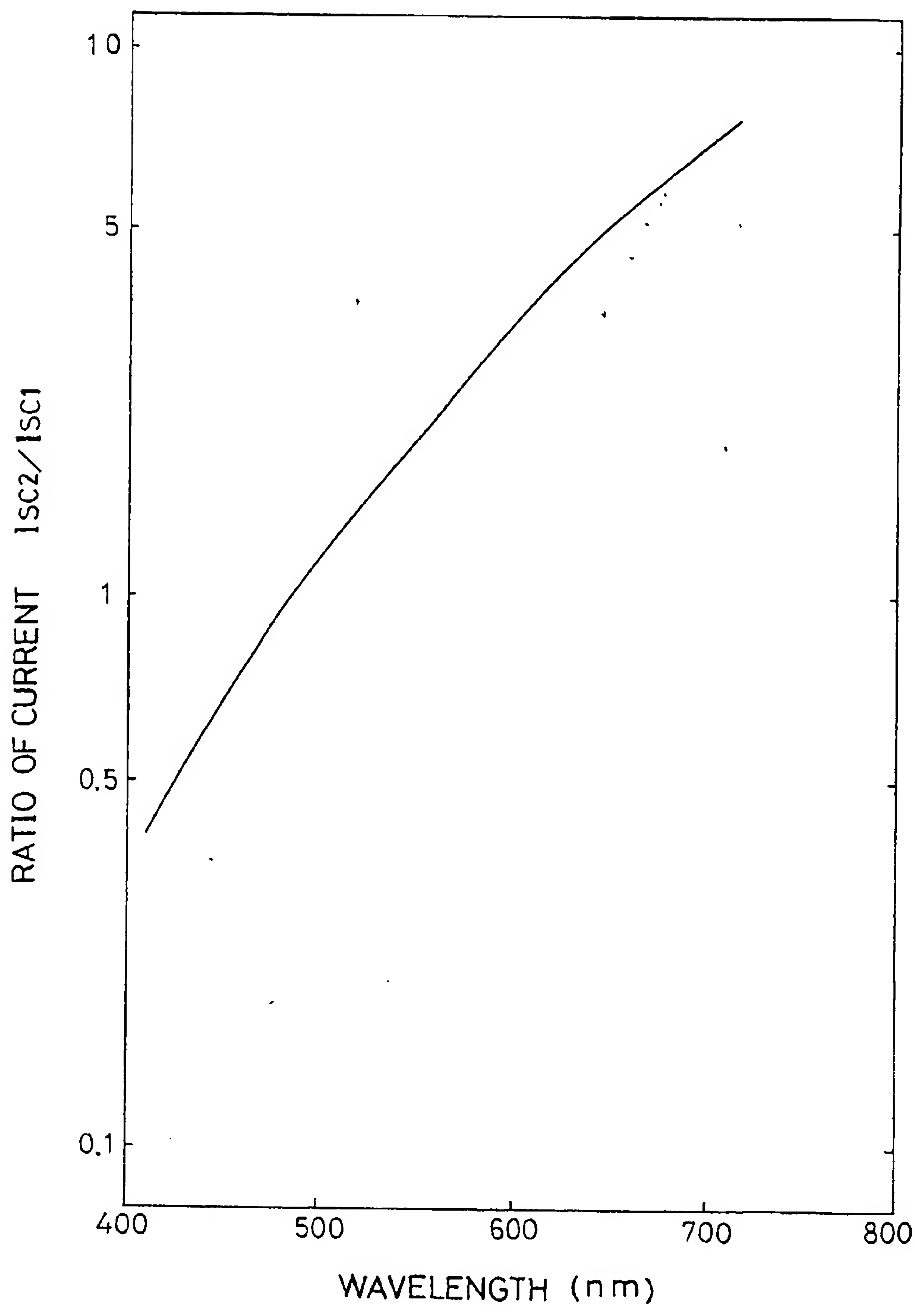


FIG. 5

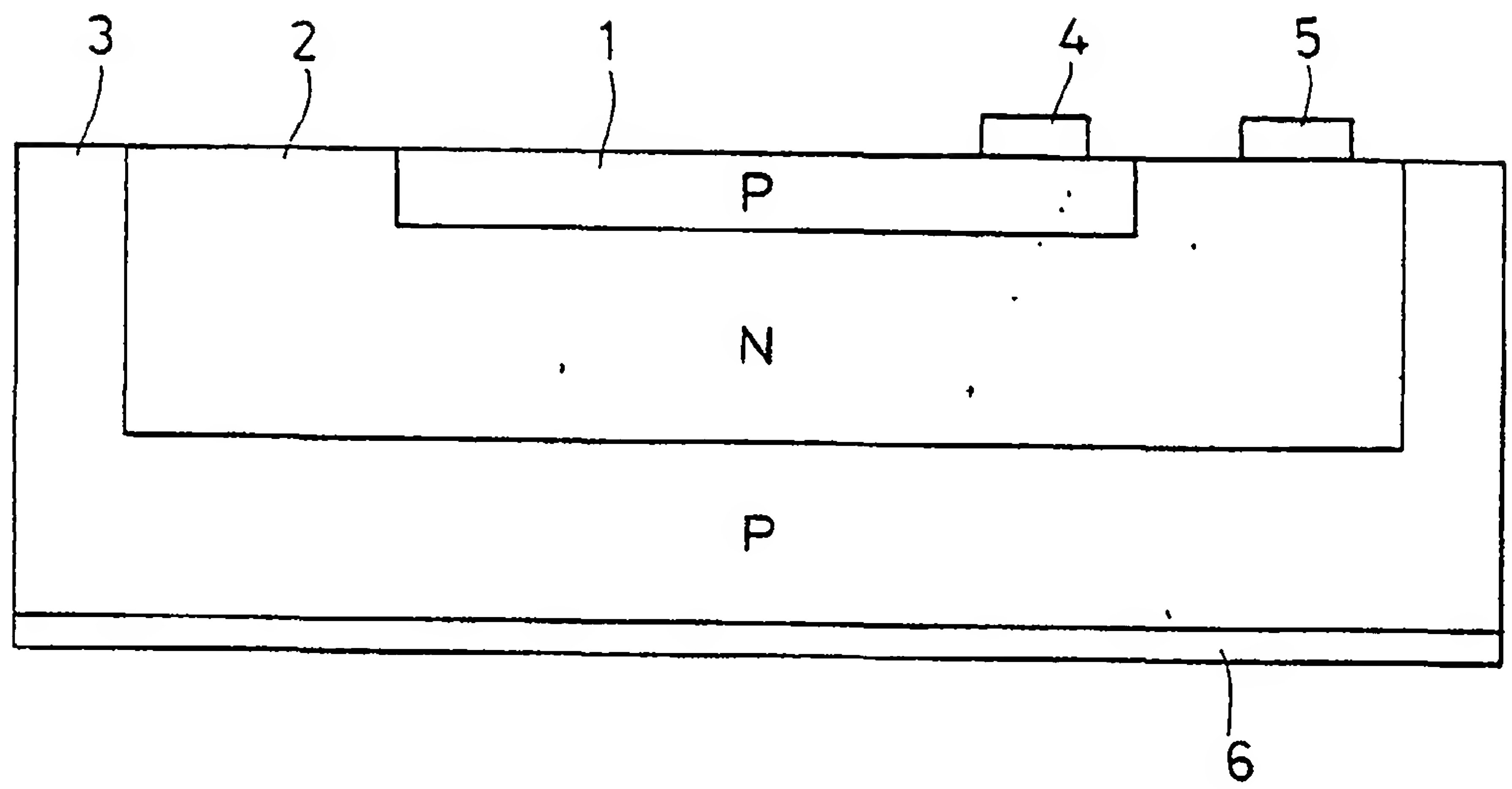


FIG. 6

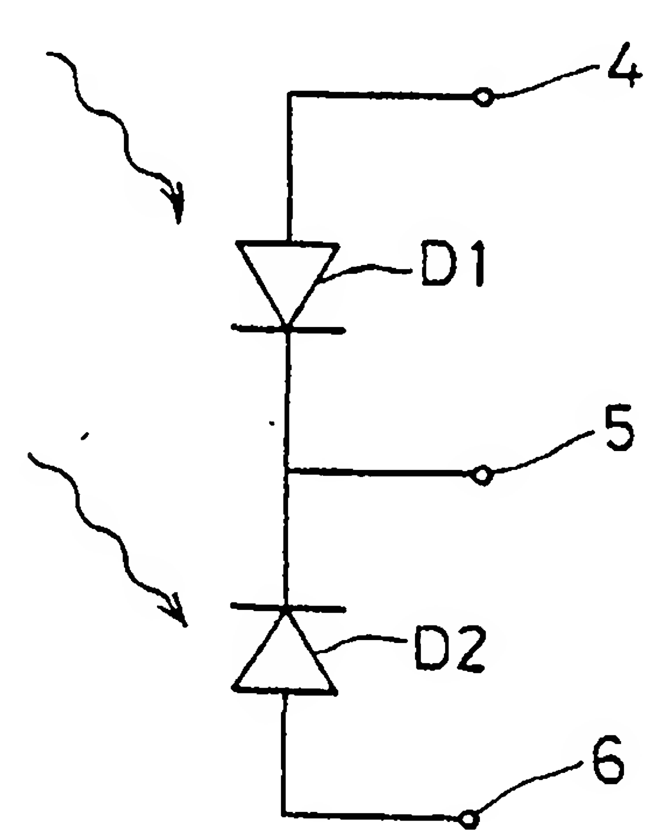


FIG. 7

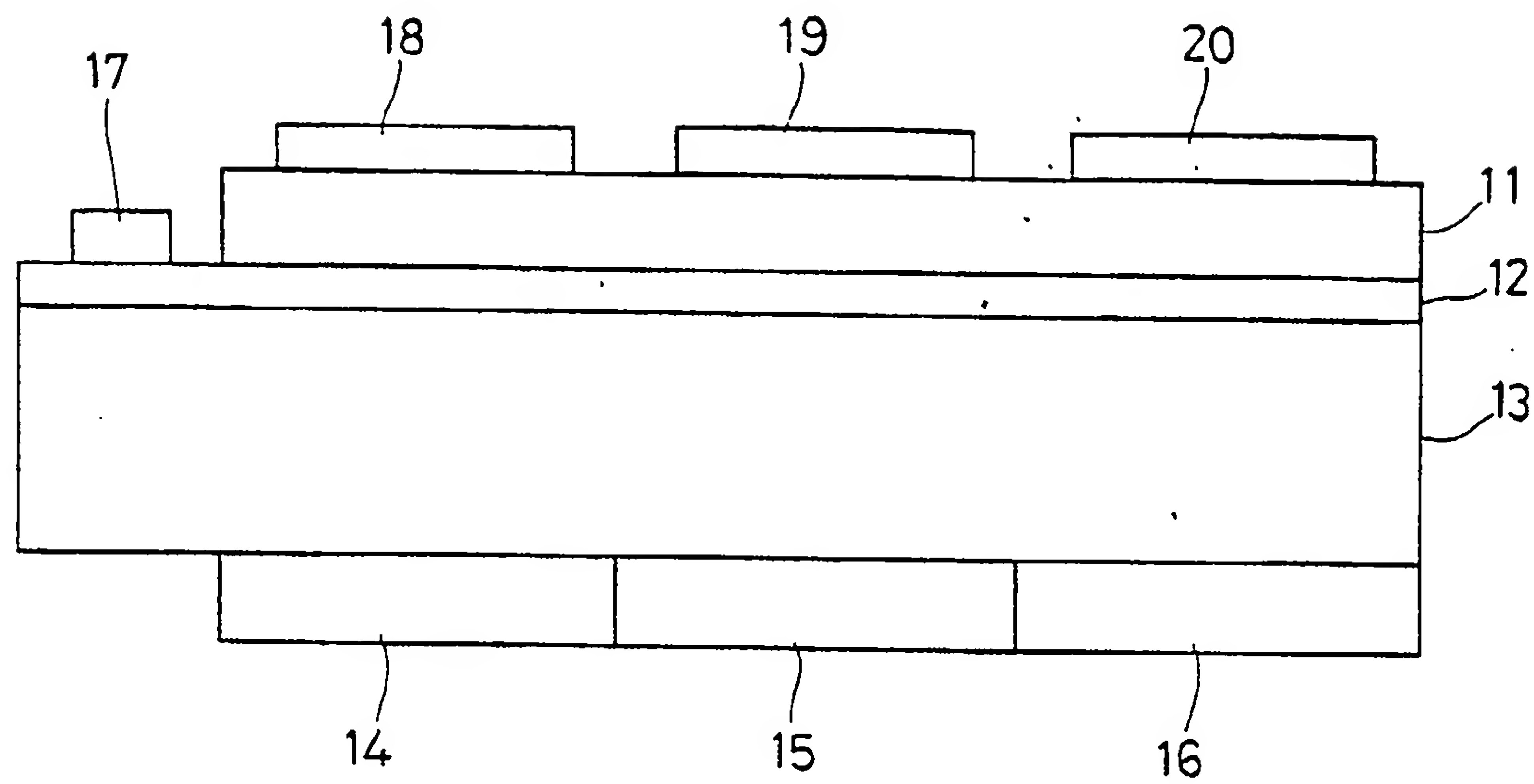


FIG. 8

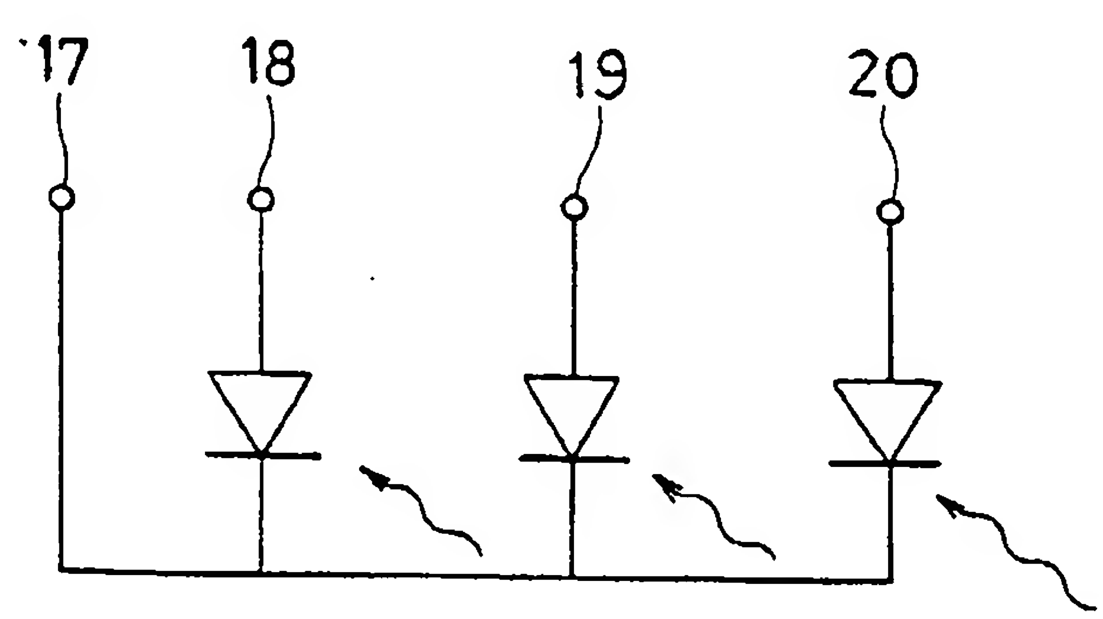
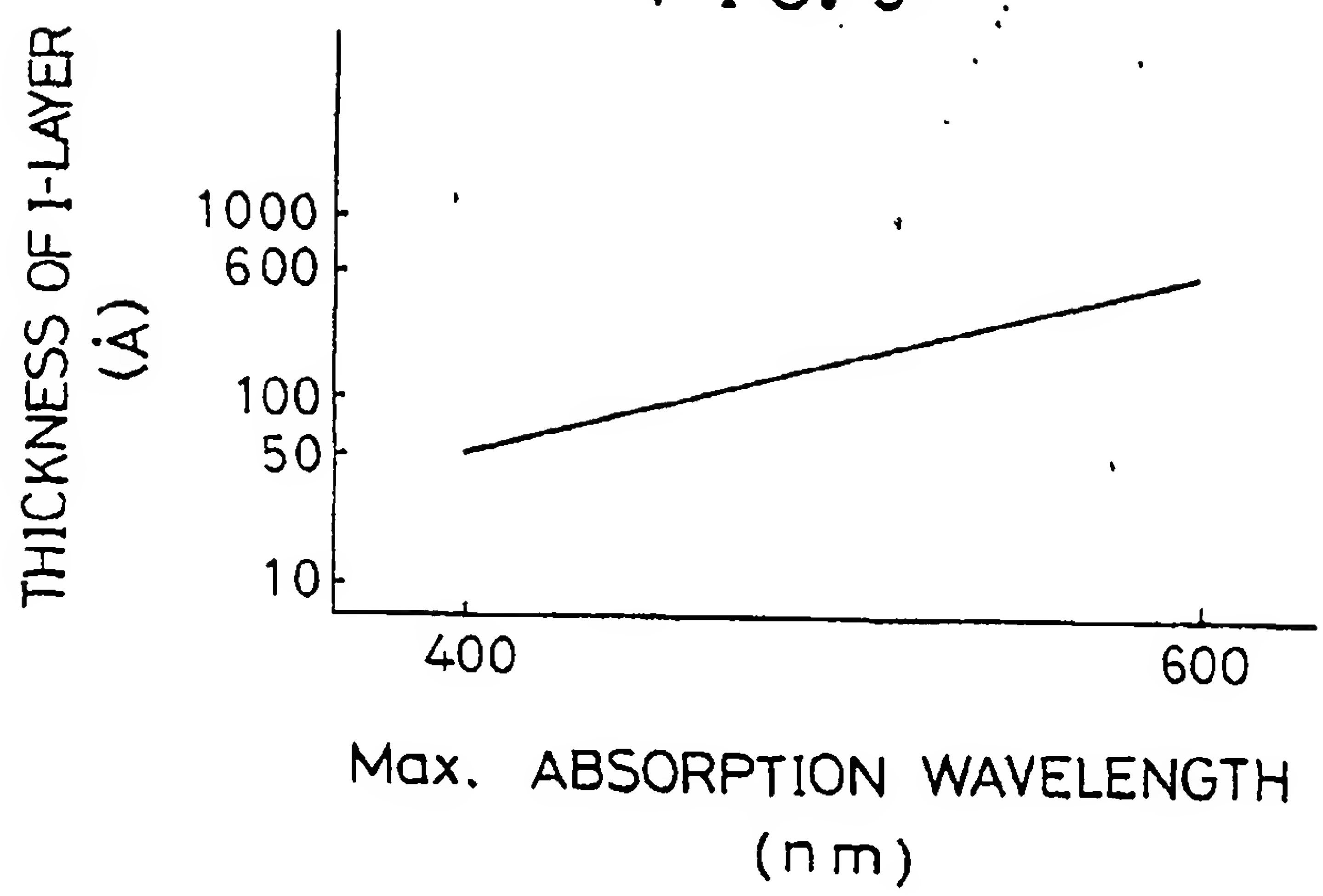


FIG. 9


THICKNESS OF I-LAYER (Å)
1000
600
100
50
10
400
600
Max. ABSORPTION WAVELENGTH (nm)

SPECIFICATION

Color sensor

Background of The Invention

Field of the Invention

This invention relates to a color sensor, and more particularly to a color sensor composed by utilizing the photoelectric effect of an amorphous solar cell which is a photovoltaic element.

Description of the Prior Art

When light is irradiated to a semiconductor substrate having a PN junction, excessive carriages are generated by luminous energy hv. The electrons and holes generated drift to the N-type region and P-type region, respectively, and while the PN junction is opened, voltage is detected by the amount equivalent to the variation of the Fermi level, and when it is short-circuited, short-circuit current flows in the direction of P-type to N-type. A semiconductor device which utilizes such a photoelectric transducing mechanism has been widely used as a photo transistor, a photo diode, a solar cell or the like.

When light is irradiated to a semiconductor substrate as described above, the absorption coefficient of light largely depends on wavelength, though the degree of dependence varies according to the materials of the substrate such as Si or Ge. Light of a short wavelength, which has large luminous energy, is absorbed in the vicinity of the surface of the semiconductor substrate, thereby generating electron-hole pairs, while light of a long wavelength reaches a comparatively deep portion and is absorbed there.

On the basis of this principle, a semiconductor color sensor which is composed of a single-crystal Si chip having receptor elements formed in a double structure therein, and utilizes the thickness of Si as a filter or uses a specific filter has been proposed and put into practice (Japanese Patent Laid-Open No. 16494/1980).

Fig. 5 is a schematic view of the structure of a conventional color sensor which uses a single-crystal silicon and Fig. 6 is an equivalent circuit diagram of the sensor shown in Fig. 5. In these figures, the referential numeral 1 denotes a P layer, 2 an n layer, 3 a P layer, and 4, 5 and 6, respectively, electrodes.

As it is clear from the figures, the color sensor shown in Fig. 5 is a semiconductor color sensor of a type which uses as a filter the thickness of Si of a single-crystal silicon chip having a receptor element formed in a double structure therein, and utilizes the difference in spectral sensitivity characteristics between a shallow junction type photo diode D1 and a deep junction type photo diode D2. As is described above, the shallow junction type photo diode D1 has large sensitivity to light of a short wavelength, while the deep junction type photo diode has large sensitivity to light of a long wavelength. By utilizing the fact that the ratio of short-circuit currents of the two photo diodes D1 and D2 corresponds to wavelength by 1 to 1, the color sensor shown in Fig. 5 can discriminate the color of the light which has entered from the upper surface of the color sensor.

In the single-crystal color sensor shown in Fig. 5, however, it is necessary to make the thickness of the silicon semiconductor layer ordinarily more than 10μm in order to obtain a desired sensitivity to wavelength (300 to 800 nm), and furthermore, a temperature not lower than 1,000°C is required for treatment of doping of impurities and thus the manufacturing process is complicated.

On the other hand, a color sensor has been proposed which uses an amorphous single-crystal silicon and color filters in combination therewith which can be formed at a comparatively low temperature (300 to 400°C) and has a thin layer as compared with a single-crystal silicon. Fig. 7 is a schematic view of an example of the structure of a conventional color sensor using amorphous silicon and Fig. 8 is an equivalent circuit diagram of the sensor. In these figures, the referential numeral 11 represents amorphous silicon, 12 a transparent conductive film, 13 a glass substrate, 14 to 16 color filters corresponding to R, G, and B, respectively, and 17 to 20, respectively, electrodes.

This color sensor can discriminate the color of the light which has entered from the filter side on the basis of the output of each photo diode corresponding to each color filter.

Such a color sensor as shown in Fig. 7 using amorphous silicon, however, is defective in that though it is possible to make the thickness of silicon smaller, it is necessary to use three kinds of color filters, and the output of a filter is apt to vary depending upon the incident angle of light in relation to the color filter and is sensitive to the influence of stray light.

Accordingly, it is an object of the invention to eliminate the above-described defects and to provide a color sensor which has a thinner silicon layer, dispenses with the need for a specific color filter and can be produced by a simple manufacturing process.

This invention is based on the unexpected finding that the device obtained by forming a receptor element in a double structure in an amorphous silicon semiconductor layer having a PIN structure exhibits wavelength dependency characteristics approximately equal to those of such a conventional single-crystal silicon device composed of a double receptor element as is shown in Fig. 5, in spite of having being very much thicnner than the conventional one. This phenomenon may be interpreted to be based on the fact that the light absorption coefficient of amorphous silicon is remarkably large compared with that of single-crystal silicon.

Summary of the invention

To achieve the above-described aim, this invention provides a color sensor comprising:

a substrate;

a first amorphous photovoltaic element having a PIN structure which is formed on the substrate;

a transparent insulated layer formed on the first amorphous photovoltaic element; and

a second amorphous photovoltaic element having a PIN structure which is formed on the transparent insulation layer.

In a color sensor according to the invention, which is composed of amorphous photovoltaic elements, the thickness of a semiconductor layer can be formed very much thinner than that of a conventional semiconductor color sensor. Furthermore, since it is unnecessary to use a specific color filter and it is possible to compose the color sensor by low-temperature treatment, the manufacturing process is simplified as compared with a conventional one, resulting in an easy and low-cost production. Such a color sensor is effective for color discrimination of colored paper, reading of color codes, color examination of pigments and dyes, color discrimination of thread and yarn, adjustment of color balance in television, color adjustment of color copy, color detection of other objects, measurement and control of color temperature and wavelength of light source, and the like.

Brief description of the drawings

Figure 1 is a schematic view of the structure of an embodiment of a color sensor according to the invention;

Figure 2 is an equivalent circuit diagram of the embodiment shown in Figure 1;

Figure 3 shows the spectral sensitivity characteristics of a color sensor according to the invention;

Figure 4 shows the dependency of the ratio of short-circuit current on wavelength;

Figure 5 is a schematic view of the structure of a conventional color sensor;

Figure 6 is an equivalent circuit diagram of the color sensor shown in Figure 5;

Figure 7 is a schematic view of the structure of another conventional color sensor;

Figure 8 is an equivalent circuit diagram of the color sensor shown in Figure 7; and

Figure 9 is a graph showing the relationship between the thickness and the maximum absorption wavelength of an amorphous photovoltaic element used for this invention.

Description of the preferred embodiment

As a substrate of a sensor according to the invention, a glass plate or a stainless steel plate is suitable.

An amorphous photovoltaic element of a PIN structure in this embodiment denotes an element composed of a P-type amorphous semiconductor layer and an N-type amorphous semiconductor layer with what is called an I-type amorphous semiconductor layer inserted therebetween. The I-type amorphous semiconductor layer is preferably as thick as possible in comparison with the P-type and N-type layers.

A first amorphous photovoltaic element is overlaid with a second amorphous photovoltaic element through a transparent insulated layer of SiO_2 or the like which is formed by deposition or the like. The thickness of the insulated layer is preferably about 0.005 to 0.1 μm.

Each of the amorphous photovoltaic elements can be produced under ordinary conditions. That is, it can be produced by a repetition of the steps of: introducing material gas for manufacturing a semiconductor under a vacuum (0.1 to 3 Torr); subjecting the material gas to plasma decomposition by plasma generated by a discharge power of 0.02 to 2 W cm^{-2}; and depositing the semiconductor film on a substrate which is heated to 150 to 300°C.

Gas having lower alkylsilane such as monosilane and disilane as the main ingredient, diborane as an impurity source, and containing hydrogen and argon, will be cited as an example of material gas for manufacturing a P-type semiconductor layer. As an example of material gas for manufacturing an N-type semiconductor layer, gas having lower alkylsilane as the main ingredient and phosphine as an impurity source and containing hydrogen will be cited. Gas having lower alkylsilane as the main ingredient and containing hydrogen is to be mentioned as an example of material gas for manufacturing an I-type semiconductor layer.

A compound semiconductor such as Ga-As semiconductor and In-P semiconductor may also be used.

The thickness of the entire semiconductor layer composed of the first and second amorphous photovoltaic elements is variable according to the wavelength range of light utilized for detection, especially according to the limit relative to a long wavelength, but with respect to ordinary light of a wavelength of 300 to 800 nm, a thickness of about one to several μm is sufficient, and preferably 1 to 2 μm. In relation to this, the relationship between the thickness and maximum absorption wavelength of the I layer of a silicon photovoltaic element to be used for this invention is shown in Figure 9. In the Figure, the abscissa represents the wavelength of light which enters and the ordinate, on the logarithm scale, the thickness of the I layer which absorbs half the quantity of the light which enters. Accordingly it is suitable to set the positions (depths) on the substrate where the first and second photovoltaic elements are to be formed by reference, for example, to Figure 9 such that respective desired long and short wavelengths are absorbed to the maximum content.

Incidentally, when light of such a long wavelength is taken into consideration, a conventional single-crystal semiconductor requires a thickness of about ten to several tens um, but in this invention about one to several μm is sufficient, as described above. That is, this invention enables the thickness of the semiconductor layer to be very much thinner than the prior art.

The polarities PIN or NIP of both laminated photovoltaic elements may be the same or opposite. The color of light which enters may be discriminated by utilizing the difference of outputs or ratios of outputs of both photovoltaic elements, and thereby an appropriate circuit may be composed.

Hereinunder an embodiment of the invention will now be explained with reference to the accompa-

nying drawings.

Figure 1 shows the structure of an embodiment of the invention.

In Figure 1, the referential numeral 21 represents a conductive substrate or an insulated substrate having a conductive thin film thereon, 22 an amorphous silicon P (or N) layer, 23 an amorphous silicon I layer, 24 an amorphous silicon N (or P) layer, 25 a transparent conductive film, 26 a transparent insulated film, 27 a transparent conductive film, 28 an amorphous silicon P (or N) layer, 29 an amorphous silicon I layer, 30 an amorphous silicon N (or P) layer, 31 a transparent conductive film, and 32, 33, 34 and 35, respectively, electrodes. On the substrate 21, the following layers are formed in lamination in the order given: the amorphous silicon P(or N) layer 22 having a thickness of about 0.05 μm and being doped with boron (or phosphorous); the amorphous silicon I layer 23 having a thickness of about 0.5 μm and which is not doped at all or which is doped with a minute amount of boron; the amorphous silicon N (or P) layer 24 having a thickness of about 0.05μm and being doped with phosphorous (or boron); the transparent conductive film 25; the transparent insulated film 26; the transparent conductive film 27; the amorphous silicon P (or N) layer 28 having a thickness of about 0.05 μm and being doped with boron (or phosphorous); the amorphous silicon I layer 29 having a thickness of about 0.5 μ and which is not doped at all or which is doped with a minute amount of boron doped; the amorphous silicon N (or P) layer 30 having a thickness of about 0.05 μm and being doped with phosphorous (or boron); and the conductive film 31. The electrode 32 is formed on the substrate (conductive) 21, the electrode 33 on the transparent film 25, the electrode 34 on the transparent film 27, and the electrode 34 on the transparent conductive film 31.

In the above structure, a first amorphous photovoltaic element (photo diode) PD2 of a PIN structure and consisting of an amorphous solar cell is composed of the P(or N) layer 22, the I layer 23 and the N (or P) layer 24, and a second amorphous photovoltaic element (photo diode) PD1 of a PIN structure and consisting of an amorphous solar cell is composed of the P(or N) layer 28, the I layer 29 and the N (or P) layer 30. In the amorphous color sensor shown in Figure 1 the two separate amorphous photovoltaic elements PD1 and PD2 constitute one chip, the equivalent circuit of which is shown in Figure 2.

The operation of the embodiment of a color sensor according to the invention shown in Figure 1 will next be explained.

Referring to Figure 1, when light (L) enters from the side of the transparent conductive film 31, the short wavelength sensitivity becomes large in the photo diode PD1, which is closer to the light receiving surface, and in the photo diode PD2, which is closer to the substrate, the long wavelength sensitivity becomes large These spectral sensitivity characteristics are shown in Figure 3.

If the short-circuit currents generated when the photo diodes PD1 and PD2 receive light are represented by I_{sc1} and I_{sc2}, respectively, the dependency of the ratio of currents I_{sc1}/I_{sc2} upon wavelength is as shown in Figure 4. That is the ratio of short-circuit currents I_{sc1}/I_{sc2} has one-to-one correspondence with respect to wavelength. Accordingly, it is possible to determine the wavelength of light which is received based on the characteristics shown in Figure 4, by measuring the short-circuit currents of the photo diodes PD1 and PD2 which flow when the photo diodes receive the light having a certain color, and obtaining the ratio of currents I_{sc1}/I_{sc2}.

CLAIMS

1. A color sensor comprising:
a substrate;
a first amorphous photovoltaic element having a PIN structure which is formed on the substrate;
a transparent insulated layer formed on the first amorphous photovoltaic element; and
a second amorphous photovoltaic element having a PIN structure which is formed on the transparent insulation layer.

2. A color sensor of claim 1 in which the first or second amorphous photovoltaic element is composed of an amorphous silicon P layer, an amorphous silicon I layer and an amorphous silicon N layer.

3. A color sensor of claim 1 in which the total thickness of the first amorphous photovoltaic element, the transparent insulated layer and the second amorphous photovoltaic element is one to several μm.

4. A color sensitive semiconductor structure comprising first and second photosensitive semiconducting elements arranged one overlying the other, each of said elements comprising overlying layers of opposite semiconducting material types separated by an insulating layer, the structure being so arranged that elements exhibit photosensitive responses with different frequency ranges.

5. A structure according to claim 4 wherein said elements are separated by a transparent insulating layer.

6. A color sensor substantially as herein described with reference to Figures 1 to 4 of the accompanying drawings.

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